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Invertebrate Animals

The commercial value of invertebrate species cannot be judged wholly by catch statistics. Peoples of the coastal areas take large quantities of food with rather little effort from shallow lagoons, estuaries and bays. Much of this they use for their own subsistence. Some they dry or otherwise preserve for future use; the rest they sell immediately near the place of fishing. Government officials find it difficult to get much information about such casual fisheries, and consequently knowledge of the consumption of invertebrates is even less accurate than that of fishes. However, it is certain that they are much less important to us than fishes for they contribute only 16 per cent of the total production of all sea food. Around four million metric tons of marine invertebrates are caught during a year.[1] Of this amount, as well as one can guess from published statistics, in which figures on invertebrates other than crustaceans and mollusks are combined with those on sea turtles, shells, lampreys and frogs, about 68 per cent are mollusks, 22 per cent are crustaceans, and the rest are sea cucumbers, sponges, worms, and jellyfishes (see Table 13-1).

More than 90 per cent of the mass of animal life in the sea is composed of invertebrates. Although there is a great variety of genera and species of which some occur in enormous numbers, few meet the requirements for usability as defined on page 227. Nevertheless, in some parts of the world, there still remain invertebrate resources which could contribute importantly to the food supply.

The food invertebrates consist now, for the most part, of oysters, clams, scallops, lobsters, shrimps, and squids. In general, people do not know about other forms, or if they do, are repelled by their strange appearance.

TABLE 13-1. CATCH OF CRUSTACEANS AND MOLLUSKS, 1953
(thousands of metric tons)

Country	All Fishery Organisms	Crustaceans	Mollusks
Africa			
Angola	222.4	0.0	0.1
French Morocco	128.0	0.5	0.7
S.W. Africa	274.8	10.3	*
Spanish Morocco	10.8	0.1	†
Union of South Africa	353.4	13.6	0.6
America, North			
Canada (excluding Newfoundland)	661.4	21.1	15.6
Newfoundland	263.3	2.0	5.2
United States	2,385.2	187.8	465.0
America, South			
Argentina (1952)	78.7	3.0	2.4
Chile	107.2	2.1	16.2
Asia			
Ceylon	25.5	0.7	2.8
Japan	4,576.5	73.4	939.9
Pakistan (1952)	126.7	6.8	*
Philippines	311.9	6.1	5.0
Europe			
Belgium	74.4	2.6	0.6
Denmark	342.8	1.6	19.9
Finland	62.1	0.1	‡
France (including Algeria)	520.3	15.7	30.9
Germany, Western	730.4	40.2	7.8
Greece	46.0	0.7	2.0
Ireland, Rep. of	19.0	0.3	3.1
Italy	213.6	6.3	23.4
Netherlands	343.3	16.9	58.4
Norway	1,505.5	6.4	0.1
Portugal	392.4	2.6	4.4
Spain	634.7	16.8	31.5
Sweden	210.0	2.8	‡
United Kingdom	1,121.6	8.0	18.1
Yugoslavia	24.4	0.2	0.2
Oceania			
Australia	51.6	8.9	4.0
New Zealand (1952)	35.3	3.4	8.5

SOURCE: *Yearbook of Fishery Statistics, 1952–53: Production and Craft.* Rome, F.A.O., 1955.

* Not reported.
† A negligible amount.
‡ Included with crustaceans.

Many species which are not edible might be good for fertilizer. Some which are poisonous might have pharmaceutical value. However, few if any, systematic technological studies are carried on to test these possibilities. Few efforts are made to arouse public interest in utilizing unfamiliar sea organisms.

In the following pages, I shall discuss the principal types of commercially valuable invertebrates and their uses.

Sponges

Sponges occur in all seas in a great range of depth and in a wide variety of forms and sizes. Although there are thousands of species, hardly more than a dozen of them have commercial value. These are characterized by skeletons composed of an organic substance called spongin.

Sponge fishing, once a substantial industry, is a victim of the technological age. In 1938, the annual world production of sponges was about 2.5 million pounds. Within ten years it had dropped to a third that volume. Production in the United States is now less than 6 per cent of what it was in 1936.[2] The development of synthetic sponges has been chiefly responsible for the downfall of the fishery. In addition, a wasting disease has at times (1938–39, 1947) plagued the grounds off Honduras, the Bahamas, and in the northern part of the Gulf of Mexico;[3] and divers have severely overfished the grounds. Chances for the recovery of the sponge industry to its former status seem slight, and natural sponges will be replaced gradually by synthetics unless some new valuable use can be found for them. If that is ever accomplished, sponge farming might be developed into a profitable venture, for these animals can be cultivated.

Sponge farming had a promising start in the Bahamas and British Honduras before the epidemic of 1937–1938 ruined the enterprise, and Japanese attempts to cultivate sponges in Caroline and other mandated islands under the Japanese occupation were promising.[4] However, it seems unlikely that artificial cultivation of sponges can be profitable on the present market.

There are some kinds of sponges which are very abundant, for which no commercial value has ever been found. For example, the loggerhead sponge of the Gulf of Mexico grows to huge size, and is a nuisance to shrimp fishermen, for it impedes trawling operations. The commercial possibilities of such species have never been thoroughly explored.

Biochemical study of the composition of sponges has disclosed the presence in some of large quantities of iodine in an aromatic amino acid contained in the skeleton, identified as 3:5 diiodotyrosine. In the red sponge (*Microciona prolifera*) it amounts to 0.3 per cent of the total dry weight. The method of accumulation of this element, present in an extremely minute quantity in sea water, still is a mystery of much scientific interest. Several organic compounds have been extracted from sponge bodies. *Crypototethia crypta,* a sponge growing in abundance around Bimini[5] contains, among other substances, the nucleosides "spongothymidine" and "spongosine." *Spheciospongia vesparia* contains metanethole, an odoriferous product responsible for the odor of many sponges.[6] Chalinasterol is found in *Chalina arbuscula,* a common sponge of the coastal waters of New England[7] and availability of this compound makes possible the preparation of the C_{24}-isomers of ergosterol and of its irradiation products. Sponges are one of the best sources of fatty acids of high molecular weight.[8] These substances are all of scientific interest to biochemists. Continued systematic chemical studies of the composition of these and other species might result in discovery of chemical compounds having medicinal or industrial value.

Coelenterates[*]

The coelenterates offer no great source of food, although one jellyfish is eaten in Korea, Japan, and China. In the Mediterranean countries and in Japan red corals are fished extensively for manufacture into jewelry and ornaments. And throughout the tropical and temperate countries various species of corals are always present in the shops which sell shells. Sea anemones are eaten in France and in some of the Pacific islands. Coelenterates possess stinging cells and some of the large jellyfishes of tropical seas and some of the siphonophores, such as the Portuguese man-of-war, are highly poisonous and contact results in serious burns. In some areas jellyfish are seasonally a nuisance to bathers. Systematic biochemical studies to identify and determine the properties of the toxic compounds in coelenterates may be of value. Although sea anemones and other coelenterates occur in vast quantities close inshore as well as on the high seas, in many parts of the world, we do not know their constituent chemicals or their potential uses.

While it does not seem probable that jellyfishes could become the object of great fisheries, nevertheless certain of them are among the most valuable animals in the sea, for they give shelter to the young of a number of species of fishes, such as hake, haddock, cod, horse mackerel, butterfish. These little fish travel with their host in the plankton, feeding around it within a radius of a few feet, darting to safe shelter beneath its umbrella when threatened by enemies. They continue this mode of life as long as it is advantageous to them, until they are ready to become independent. This association may be an essential stage in the life cycle of some fishes; that is to say, if they fail to find a jellyfish within a certain time, they probably perish. In spite of the probable importance of this relation, it is astonishingly neglected in research programs.

Echinoderms

As a source of food the echinoderms are of relatively little significance. Only a few species of sea cucumbers (trepang or *bêche de mer*) are extensively fished in the Orient. These belong to the families Stichopidae and Holothuriidae. Several species are used as trepang. At least one (*Stichopus chloronotus*) is used for fertilizer. Another, *Cucumaria minata,* sometimes finds its way into soup as an important ingredient, if not the principal one, in clam chowder on the west coast of America.

In Japan, one species of sea cucumber, *Stichopus japonicus,* is raised on trepang farms and research is in progress to develop methods of artificial propagation from larvae.[9]

The trepang will continue to be popular in the Orient, but it seems doubtful that sea cucumbers are abundant enough to be of major importance. Not all species are edible. Many are too small to be useful. At least one species is deadly poisonous.

The ripe gonads of sea urchins are frequently used for food, but are scarcely of great importance as a food resource. The importance of sea urchins as a material for scientific research, however, far exceeds their usefulness as food. *Arbacia* of the North Atlantic coast and several species of *Strongylocentrotus* and the sand dollar *Echinarachinius* are used as experimental animals in studies of cellular physiology, biochemistry of ova, fertilization processes, and experimental embryology. Eggs of these species, and particularly those of *Arbacia,* continue to be the most desirable material for research in many marine laboratories.

Most, if not all sea urchins have poison glands, but in only a few is the quantity of poison great enough to be serious to man. Sometimes, for instance, large quantities of the common green sea urchin *Strongylocentrotus dröbachiensis* become caught in trawls; and then the handling of such large numbers is an irritation to fishermen.

The species of *Toxopneustes* found in East Africa, Fiji, New Caledonia, Japan, and from the Gulf of California to Colombia have powerful poison glands in their large and numerous pedicellariae. These sea urchins are much dreaded by fishermen, for occasionally they cause fatalities.[10] The spines on *Diadema* and one species of Echinothrix are very poisonous. So are the spiny projections of the starfish *Acanthaster.* Here again, pharmacological and chemical studies of echinoderm toxins are desirable, not only from the viewpoint of human safety, but also because those animals might prove to be a valuable source of new and physiologically important chemical compounds.

Mollusks

Among all major groups of invertebrates, mollusks probably offer the greatest opportunity for expanding the harvest of seafood resources. The shores of all countries are populated with sedentary mollusks, some crawling about the bottom, others buried in the sand or mud, still others attached to such solid objects as rocks or the shells of their forebears or the roots of mangrove trees. Most of them are easily and cheaply harvested, for they can be picked up by hand during low tide or grabbed with simple gear such as tongs, from small boats working in shallow water. Nevertheless, many of these are not utilized, often because people are ignorant of their value. Other mollusks, notably squids, are not sedentary but behave like fish, traveling in the open sea in dense schools. These can be caught with purse seines like herring, and where they are exploited, they support large and profitable fisheries. Mollusks are not universally appreciated, and in places where they are appreciated they are often improvidently harvested, with consequent depreciation of their productivity.

Oysters. Many species of oysters, of which there may be a hundred or more, are widely distributed in temperate, subtropical and tropical regions, mostly between the forty-fifth parallels north and south of the equator, but also, thanks to the moderating influence of the Gulf Stream, as far north as about the sixty-second parallel on the European side of the Atlantic. In North America, Europe, and in parts of Asia, they are exceedingly valuable. In the United States, for instance, the annual harvest brings more than 32 million dollars to fishermen. In many regions, particularly in the southern hemisphere, oysters seem to be far underexploited; indeed, little is known about their distribution, abundance, or commercial potentialities. It is reasonable to expect that explorations and studies along the coasts of Brazil, Peru, Chile, and the east coast of Africa would disclose valuable latent oyster resources and perhaps stimulate new industries in those countries.

In many areas wild oysters are gathered from natural bottoms without any effort to maintain the productivity of the stock. About a third of the harvest in the United States waters is obtained in this way. It is a foolish and destructive method, leading to unnecessary dimunition in the profitableness of the resource, as exemplified by the decline in production on the Atlantic coast of the United States. The most promising way to sustain the yield of oysters is to farm them, as is done in some areas of the United States, and in Japan, England, France, Italy, the Netherlands, Denmark, Australia, and the Philippines. Even where oyster farming is most advanced, however, a great many problems must be solved to minimize variation in production and quality, to control the many diseases, parasites, and predators which plague oysters throughout life, and to improve the fertility of the grounds.

As practiced today, cultivation depends largely on the ability of the oyster grower to place at the right time and place sufficient quantities of clean, hard material for the attachment of free-swimming oyster larvae.[11] To accomplish this it is necessary to determine in advance and with accuracy the expected time and intensity of setting. Work in this country and in Europe has developed some practical schemes which make it possible to anticipate the time of setting. It has not, however, attained any degree of success in predicting the survival of oyster larvae and frequent failures of oyster sets remain unexplained. Every theory so far advanced to explain the setting behavior of oyster larvae seems applicable only to some particular case and becomes untenable when applied to other situations. The apparent preference of oyster larvae to set in certain localities in a rather narrow zone of tidal flats is particularly mysterious. Large concentrations of newly attached oysters are often observed at a level of 1 to 2.5 feet above mean low water, while in other locations such selectivity in vertical distribution of setting is lacking and young oysters are more or less uniformly distributed on the bottom from low water mark to depths of 20 feet or more.

Oysters and other shellfish are subject to wide seasonal fluctuations in the chemical composition of their meats. A yield from a bushel of oysters gathered from the same location at different times of the year may be as low as 2 pounds of meat or as high as 8 and 9 pounds. Total solids may vary from 10 per cent in poor oysters to more than 20 per cent in good ones. Changes in the total solids are accompanied by corresponding fluctuations in the content of tissue-bound water. Total carbohydrates, particularly glycogen, vary, depending on the season and location of grounds, from less than 0.5 to about 8–9 per cent of wet weight.[12] Likewise, there are conspicuous seasonal and geographical differences in the content of copper, manganese, zinc and iron. The control of such variation is one of the principal subjects of research needed for the improvement of oyster farming. Another is oyster genetics. This cannot go forward for any species until a reliable and practical method of voluminous artificial propagation of seed oysters is developed. When that problem is solved, it should be possible, by selective breeding and hybridization, to produce strains characterized by rapid growth, high glycogen content, thin shell, disease resistance, and other features that may materially improve the quality of commercial oysters and increase their yield.

MUSSELS. Several species of mussels (*Mytilus*) are widely used for food in all European countries and to a lesser extent in North and South America, Australia, and South Africa. Probably fairly large quantities of mussels are eaten in the Orient, but production statistics are not available.

Mussels are extraordinarily fertile, and the productivity of mussel grounds far exceeds that of the best oyster bottoms. They are capable of forming in a short time large, thickly layered beds covering the bottom. Demand for them in Europe for food and bait at one time was so great that natural mussel beds were inadequate to supply the fishery and much attention has been given since to mussel culture, especially in France and Italy, where the ancient system of "bouchots" or fences made of twigs set in shallow water for the attachment of mussel larvae is still in use. Because of the prolonged reproductive season and very rapid growth of mussels in the Mediterranean Sea, the cultivation of mussels is a continuous process. Each generation becomes mature within sixteen to nineteen months and new generations are well under way when the old one is harvested. French mussel growers report that about 150 kilograms of mussels may be taken from each linear meter of "bouchot." In the Bay of Taranto, Italy, where mussel culture is highly developed, the productivity has averaged 1,215 kilograms per 100 square meters, or 49 metric tons per acre.[13]

Mussels have relatively thin shells and consequently the edible portion of their bodies is relatively greater than that of the oyster. According to Atwater and Bryant (1906) the waste material comprises only 46 per cent of the total weight of mussels while it constitutes more than 90 per cent in oysters. Much more food material may be obtained from the sea by growing mussels than from any other edible shellfish.

Improvement in the production of mussels requires research to develop methods of controlling parasites, diseases, and predators and, where farming is practiced, of propagating seed. In certain areas, mussels are occasionally infected by poisonous dinoflagellates and then are dangerous to eat. Where this happens, the possibility of controlling the sporadic blooms of the poisonous organism, perhaps by chemical means, should be thoroughly explored.

CLAMS, SCALLOPS, COCKLES, AND OTHER LAMELLIBRANCHS. Clams of many species and genera are used for food all over the world.

They are exceedingly nutritious, easily reached and cheaply gathered. If harvested at a proper rate, under regulations based on biological information, clam beds can be highly productive. Otherwise they are particularly vulnerable to overfishing. Clams are also vulnerable to a considerable assortment of predators, of which the most terrible are boring snails and crabs. Unfortunately the crabs are usually too small to have commercial use. Clams are among the animals that can be profitably cultivated; in fact that is the principal means of production in Japan. By growing clams under protected conditions it is possible to minimize predation by pests, and to harvest them as the market demands at their most profitable size. The same kinds of research problems apply to clams as to oysters, namely, methods of artificial cultivation, selective breeding, methods of controlling enemies, and methods of improving the fertility of beds.

In the United States several species of clams are the object of important fisheries on both Atlantic and Pacific coasts, and intensive research programs are aimed particularly toward designing regulations for rational conservation, and toward the control of predators.

In the tropical zone of the Pacific the giant clams, *Tridacna,* and the related genus *Hippopus,* a horse-hoof clam, which live either embedded in coral reefs or lie unattached on the surface of reefs, are regularly used for food.

The utilization of the window shell, *Placuna placenta,* in the Philippines deserves special attention both because of the extensive use of this mollusk in home construction and the success in its cultivation in Manila Bay where the high yield of the fishery is maintained primarily by extensive farming methods. *Placuna* is widely distributed through the Philippine Archipelago. It inhabits the bottom from the littoral zone to a depth of 300 feet. For centuries its thin semitransparent shells were used in oriental countries as a substitute for glass. At one time about half of the houses in Manila had *Placuna* shells in their windows. This city still uses several million shells annually, while large quantities of them are exported to India, Ceylon, and China.

Placuna farming, practiced in the Philippines, consists in gathering the young from their natural beds and planting them on suitable ground. They thrive on muddy bottoms and grow very rapidly. The meat of *Placuna* is palatable and is frequently eaten, although it is usually not sold in fish markets. The yield from a good *Placuna* farm is said to be twice as much as that from an oyster farm of the same size. Frequently both oysters and window shells are grown on the same grounds. Periodic mortalities strike *Placuna* populations. Filipino fishermen frequently report finding large numbers of shells buried in mud. Like many other mortalities of marine populations the cause of this one has not been determined.

Many species of scallops and cockles (*Pecten* and *Cardium*) are widely distributed throughout the world, from the arctic to the tropics. Their habitat extends from shore to at least 450 fathoms.

Although scallops are able to swim, by a peculiar rapid clapping of their valves, they seem not to migrate very far and usually remain within a relatively limited distance of their beds. As a rule they prefer hard and sandy bottoms but occur also on mud and among rocks. Some species of scallops live in shallow inshore waters and are easily caught with rakes and light dredges operating from small boats; others live offshore in greater depths, and require heavier gear and larger vessels. Bay scallops may be particularly vulnerable to overfishing. To guard against this the rate of fishing must be regulated to produce the highest sustained yield.

Scallops are particularly appreciated in the United States. On the United States Atlantic coast, 24 million pounds are caught in a year, worth about 13 million dollars. Much smaller quantities are caught in the United Kingdom, Ireland, France, Oceania, and Japan. Elsewhere scallop resources are quite neglected.

The scallop has provided material for the study of many interesting physiological problems. Gill epithelium, adductor muscle, and eyes have received special attention. No other organ of mollusks has given rise to more discussion than the complex scallop eyes. Since their discovery over 150 years ago these remarkable organs, arranged in a row on the edge of the mantle, continue to excite the interest of zoologists, anatomists and physiologists. The gill epithelium of scallops is a favorite object for study of the physiology of ciliary motion. The search for the nervous control of ciliary beat is a problem of wide interest because ciliary motion is involved in physiology of vertebrates (including man) as well as of lower animals.

The use of cockles (*Cardium*) is limited. Although gathered for food in Europe and in some oriental countries they are almost completely neglected in the United States. Fisheries for cockles, as for many other kinds of mollusks can be materially expanded in many areas with the help of market development programs.

The principal source of pearls is a lamellibranch mollusk of the genus *Pinctada* which differs from the true oysters by the presence of a byssus, by which pearl oysters attach themselves to the substratum. The mother-of-pearl fishery is of considerable economic importance, providing raw material for buttons and decorated articles for which there is a fairly stable market. Commerce in pearls, on the other hand, is much affected by the fluctuations in price and market demands.

It is doubtful that new, rich pearl oyster grounds can be found, since for centuries all waters likely to contain them have been searched intensively. Important fisheries are located in the Red Sea, Persian Gulf, Ceylon, Sulu Archipelago of the Philippines, Australia, west coast of Mexico, Panama, Venezuela, Hawaiian Islands, and the Gulf of California. The Japanese pearl fishery occupies a unique position because of the highly developed cultivation of pearl oysters and artificial induction of pearl formation.[14] All pearl oysters are edible; their use for human consumption is gradually increasing and meats formerly discarded as refuse are in some places preserved by canning or drying.

SNAILS. Marine snails can be utilized for human needs to a much greater extent than is generally known. In North America they are almost completely neglected; in Europe a few forms such as periwinkles, whelks, and limpets are used for food. In the Orient many more species are eaten, including large whelks and conchs. In the Philippines small fresh-water gastropods are fed to ducks on the many duck farms near Manila. The principal product of the farms is not the duck meat but duck eggs, which are permitted to develop nearly to a hatching stage and are then preserved by boiling and sold as "balut." Parasitological study of the snails used to feed the ducks as possible vectors of various trematode diseases of man and domestic animals is of importance because of the known role of gastropods in transmitting schistosomiasis and other diseases.[15]

Large marine gastropods of the family Trochidae are important sources of material for button manufacture and other shellcraft. In Australia *Trochus* shells are extensively used for jewelry, and *Trochus* meat is used for food throughout the area of its distribution in the tropical seas.

There are many species of carnivorous marine snails which live by boring holes in the shells of other mollusks, particularly oysters and clams, and feeding on their flesh. In this way they inflict terrible damage in commercially valuable areas all over the world, in the tropics as well as in temperate latitudes. Control of such pests would do more than anything else to improve the productivity of shellfish grounds. This is an exceedingly difficult problem to solve, however, for these animals are prolific, hardy, and widely distributed. Detailed studies of the habits, reactions, growth, reproduction, diseases, and enemies of these snails are needed to develop methods for their control. Commercial uses should be sought; for some of them are not only edible but palatable, though rarely eaten and not sold in the markets.

ABALONES. The abalones (*Haliotis*) are one kind of gastropod which is extensively used for food. These animals, of which there are several species, are fished on the Pacific coast of North America, as well as in China, Japan and Korea, and to a lesser extent in the Union of South Africa and in southern Peru. They tightly adhere to rocks under water and can be dislodged only by divers using crowbar or chisel. These mollusks are highly appreciated wherever they are fished. It does not seem likely that there are many accessible unfished stocks which could add significantly to the world's food supply.

CEPHALOPODS—SQUIDS, CUTTLEFISH, OCTOPUS. About 1,800,000 metric tons of mollusks are harvested annually in the world, which is over 70 per cent of all the invertebrates harvested. More than a quarter of these are squids. There are many species of these animals; they range in size from pygmies of a few centimeters to giants of over 15 meters. They are widely distributed, horizontally along shores as well as on the high seas, and vertically from surface down to great depths. They are evidently exceedingly abundant, as shown by the fact that squids are one of the important fodder animals of fishes. Even the giants, which are rarely seen by man and then generally only as dead specimens washed upon beaches, are probably also abundant, for they are one of the principal foods of the great whales. Squids are highly predacious themselves, feeding on fishes and pelagic invertebrates. Hence they are competitors of fishes in the economy of the sea. The species which are most familiar to fishermen grow to be 20 or 30 centimeters long and are pelagic, traveling in large schools at the surface. They seem to be enormously abundant and are nutritious and palatable.

Recently squids have become important in neurophysiological research because of the presence of giant nerve cells which greatly simplify experiments in neuromuscular transmission. Demands for live squid have become so great that it is difficult to satisfy the needs of experimental laboratories and organizations engaged in this research. Neurophysiological studies of the nature and mechanism of nervous impulses contribute to the advance of human physiology and have broad application in medicine.

Cuttlefish are similar to squids but differ in having a heavy calcified internal shell or bone, as contrasted with the thin "pen" of the squids. They, too, are caught for food and bait. In addition, their internal shell is manufactured into a powder for polishing and other industrial purposes and for dentifrice. The whole shell in "cuttlebone" is sold for feeding cage birds. The ink sac of cuttlefish is a source of the natural brown pigment called sepia.

Octopi are much less abundant than squids. They are shore-dwelling animals, occurring around sea coasts all over the world. They are caught with traps and used extensively for food in countries of the Orient and in southern Europe. Elsewhere they are not appreciated and almost completely neglected. They could add something to the world's food supply, but not very large quantities.

People who have never tasted squid, cuttlefish, or octopus generally look on them with abhorrence. This prejudice is the first obstacle to starting fisheries for these animals. It could be overcome by market development programs, by advertising, cooking demonstrations, and most important of all by the development of attractive marketable products.

Before the war the Japanese squid fishery took 75,000 to 150,000 tons annually; in recent years, their catch has grown to a peak of 600,000 tons. In North America where squid stocks may be equally large, less than 6,000 tons are caught, most of it on the Pacific coast. Southern European countries, chiefly Spain, Portugal, Italy, and Yugoslavia, take about 20,000 tons. The rest of the maritime countries take inconsequential amounts. Thus squid might be one of the most promising of the unutilized fishery resources. In Japan and in western United States squid are sold fresh, dried, and canned, and are also used as bait. They might be a good raw material for protein meal. In Europe and western America they are caught by encircling nets, and in Newfoundland and in Japan they are snagged on hooks. In Japan, squid are fished at night, being attracted and concentrated by the use of lights. Since they swim in schools, come close to shore, and can be easily caught with simple equipment, they are the object of a very intense fishery conducted by coastal dwelling families operating small boats in the southern part of Hokkaido (northern Japan). There squid constitutes as much as 60 per cent of the total catch of sea food. As fisheries for squid and octopus developed, it would be important to study the ecology, life histories, behavior, and migratory patterns, to measure the rates of birth, growth and mortality, and to determine the effects of fishing on abundance of the stocks.

Crustacea

Of many thousands of marine crustacea only a few species, belonging mostly to the order Decapoda, are of economic importance now. The lower groups, immensely abundant in the sea, for the most part are only indirectly concerned in human economy either as food for fishes or as such nuisances as the organisms fouling ships' bottoms (barnacles) or those boring into wooden hulls and piling (wood-boring isopods).

PRAWNS AND SHRIMPS. Of all the edible decapods, prawns and shrimps* are by far the most important. They occur in estuaries, in fjords, in areas of continental shelf that are nourished by rivers, and sometimes on offshore banks. The greatest fishery for prawns is in the United States, where (called shrimp) they are the most valuable of all the sea foods. The annual catch in the South Atlantic and Gulf states, where the principal fishery is carried on, is now around 250 million pounds.

At least 22 species of shrimps and prawns are fished commercially. There are important fisheries for these animals in the United States, West Indies, coastal European countries, along the central American and South American coasts, and throughout the Indo-Pacific area.

Perhaps in many areas where they occur, shrimp and prawns are underutilized. This is a possibility which can only be tested by experimental fishing. Exploratory fishing and development of new gear and fishing techniques are important activities for future investigations. Efforts made so far in these directions have had some promising success judging, for instance, from the discovery of populations of northern shrimp, *Pandalus borealis,* along the New England coast,[16] of the pink shrimp (*Penaeus duorarum*) near Key West, Florida, and of the "royal red shrimp," *Hymenopenaeus robustus,* in 200 fathoms off the Florida coast.[17] Further exploration may result in discovery of untapped shrimp populations which may materially add to our food resources.

Prawns and shrimps tend to live in parts of the sea that are fertilized by land drainage, such as estuaries, fjords, and bays. A pattern of life history, which is common to many of the species (perhaps to all peneids), is this: They enter the inshore waters and estuaries at very young stages; for a few months they live in these nursery grounds while they grow very rapidly. Just before maturity they migrate to sea, where they spawn. Perhaps they die after spawning; at any rate they do not return. Thus they are short-lived fast-growing animals, a fact which gives them special value as a food resource, for it makes them less vulnerable than other species to intense fishing (see also pages 45 ff.). Perhaps the most useful line of prawn research would center about the inshore nursery areas. What controls their productivity? What are the competitors

* The large species, mostly belonging to the genus *Penaeus,* are prawns.

and predators of the young prawns? What is their food? What are the optimum densities of prawn stocks? Why must the prawns go to sea to spawn? Could they be induced to spawn in enclosures? Would artificial culture be a profitable enterprise?

LOBSTERS. These crustaceans are the object of fisheries in Europe, America, the West Indies, South Africa, Australia, and Japan. They are probably not vastly abundant anywhere, but they are much appreciated and high-priced wherever they occur. The principal species are the true lobsters, *Homarus americanus* and *H. vulgaris;* and the spiny lobsters (crawfish or crayfish)—*Panulirus argus* (Florida, the Caribbean area, the Atlantic coast of South America, *P. interruptus* (Southern California), *P. rissonii* (western Mediterranean and West Africa), *P. japonicus* (Japan and Hawaiian Islands), *P. inflatus* (west coast of Mexico and Hawaii), *Jasus lalandei* (Australia, Juan Fernandez Islands, New Zealand, and South Africa), *J. verreauxii* (southern Australia and New Zealand), *Palinurus elephas* (Europe), *Panulirus penicillatus* (Indo-Pacific and Korea), *P. longipes* (western Australia); likewise the deep sea shrimp or Norway lobster, *Nephrops japonicus* (Japan and Korea), and *N. norvegicus* (in deep water off the coast of Norway).

Several unsuccessful attempts to introduce the Juan Fernandez lobster to the coast of the mainland have been made. Expansion of the spiny lobster fishery in Australia and New Zealand is likely to continue for some time and unexploited populations may be found along the coast of Chile and Peru. Although it is doubtful that the yield of the American lobster can be increased, spiny lobsters seem to be underutilized. This is a possibility that could be tested by exploring likely fishing areas near Mexico, Central and South America, and the islands of the Pacific.

Artificial propagation of lobsters attempted by government agencies does not seem to be promising. The post-embroyonic development is complex and slow, and the rate of infant mortality in captivity is discouragingly high. Furthermore, the growth rate is so slow that raising them in captivity to maturity would probably be a prohibitively expensive undertaking. It seems better sense to support the lobster populations on their own natural grounds by controlling fishing rates. This necessitates measuring the rates of growth, birth, and death, the size of stocks, and the effect of fishing thereon.

It is very difficult to do this with crustaceans, for they molt in growing, and in doing so, often throw off any tag that has been applied to their shell. How, then, can we learn their routes of migration or measure the size of their population and their rates of growth and replacement? Another difficulty is that they do not record their age on parts of their body as fishes do. Consequently, special methods must be developed to permit analysis of the age composition of samples, which is an essential part of population dynamics studies. The development of such techniques must be the object of special research. This is true for crabs as well as for lobsters.

CRABS. There are many species of crabs used for food but only a few of them are taken in quantities large enough to be recorded in statistics. Among the most important species are the blue crab of the Atlantic and Gulf coasts of the United States (*Callinectes sapidus*), Dungeness crab of the Pacific coast (*Cancer magister*), the giant crabs of Alaska, the Bering Sea, Japan, and Kamchatka (*Paralithodes camtschatica, P. platypus,* and *P. brevipes*), the red crab, (*Chionectes opilio*), and the blue crab (*Neptunus trituberculetus*) of Japan.

It seems likely that some of the crab resources of the Americas are not fully utilized and that new fishing grounds may be located by exploring the continental shelf and the inshore waters. Information about crabs in the Indian Ocean, Philippines, Australia, and South Africa is too meager to encourage any speculation regarding their potentialities.

BARNACLES. The principal fouling organisms on ships' bottoms and on floats of hydroplanes, barnacles make for costly maintenance throughout the world. Antifouling measures, scraping and repainting of ships' hulls, and the use of antifouling materials cost millions of dollars annually. There is, however, a species of large sessile barnacle, *Nalanus psittacus,* common on rocks of the coast of Chile which Darwin described as "universally esteemed as a delicious article of food." Another edible species is the goose barnacle, *Mitella pollicipes,* used for food along the coast of Brittany, Spain, and the Mediterranean. Economically these species are of little significance.

TUNICATES. These organisms are widely distributed in the ocean and flourish in tropical and subtropical seas. On an evolutionary scale tunicates occupy a unique position as predecessors of vertebrates. One of the characteristic anatomical features of tunicates is the presence of a tough tunic made of the animal cellulose tunicin. The body inside the tunic is soft and watery.

Tunicates are of slight if any economic importance. Free-swimming forms like Appendicularidae and ascidian larvae are eaten by fish and therefore indirectly contribute to the supply of human food. Sedentary ascidians are edible and occasionally are used by people living in tropical islands. Species of the family Cynthiidae are fished for food in various parts of the world, for example, Japan, China, Siberia, and southern France.

Tunicates are unique in several respects. One of their most interesting features is the ability to concentrate in their bodies the rare metal vanadium, which is found in the sea water in low concentrations (0.2–0.3 milligrams per cubic meter).[18]